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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : H04Q 3/52, G02B 26/02

A1

(11) International Publication Number: WO 99/45719

(43) International Publication Date: 10 September 1999 (10.09.99)

(21) International Application Number: PCT/US99/04488

(22) International Filing Date: 1 March 1999 (01.03.99)

(30) Priority Data:
09/034,818 4 March 1998 (04.03.98) US

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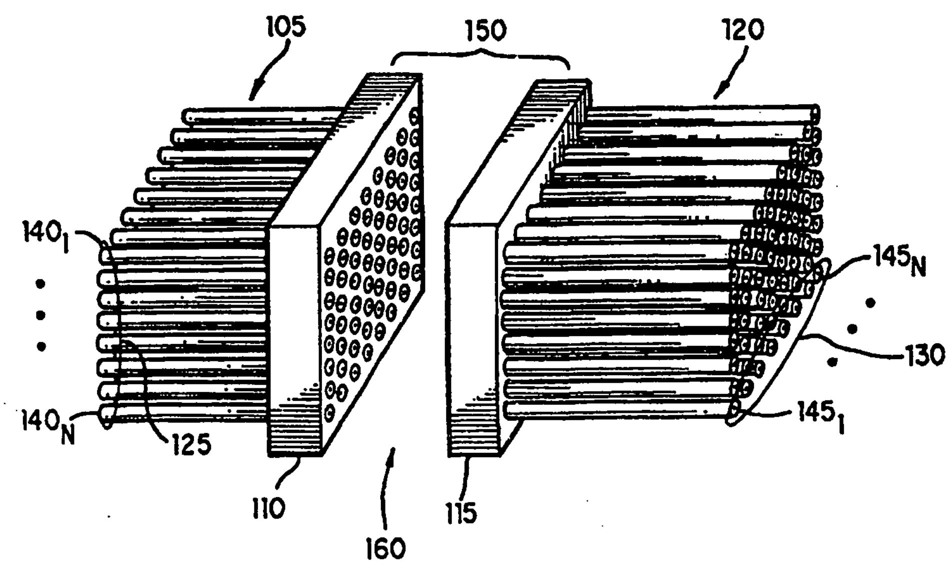
(81) Designated States: AU, CA, CN, JP, European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

Published

With international search report.
Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.

(54) Title: OPTICAL SHUFFLE NETWORK INTERCONNECTION



(57) Abstract

A three-dimensional switch interconnection structure for connecting a shuffle network which includes a first set of optical transmission members arranged in a first direction; a second set of optical transmission members arranged in a second direction; and a connection unit which couples each of the first set of transmission members to a corresponding one of the second set of transmission members. The use of this interconnection structure together with fiber ribbon cables avoids the mesh of connections associated with previous switching connections.

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OPTICAL SHUFFLE NETWORK INTERCONNECTION

FIELD OF INVENTION

The present invention relates generally to optical communication systems and more particularly to a structure and method for interconnecting a plurality of optical switches.

BACKGROUND OF INVENTION

Optical communication systems are a substantial and fast-growing constituent of communication networks because of their large transmission bandwidth and low signal losses. Currently, the majority of optical communication systems are point-to-point networks configured to carry optical signals over one or more optical waveguides from a transmit terminal to a receive terminal. The use of optical communication systems has also expanded into local network architectures, such as local area networks (LANs), metropolitan area networks (MANs) and wide area networks (WANs).

Currently, communications networks employ optical fiber as the transmission medium and electronic devices for processing of the received signals. In this type of network, switching is performed by electronic components where the optical signals transmitted over a fiber are first converted to their electronic equivalent and subsequently processed. However, electronic switches are better suited for use at transmission data rates lower than the current state of the art. This necessitates electronically demultiplexing the signals, performing the switching, then multiplexing the signals up to the transmission rate. A drawback associated with these switching systems is the introduction of unwanted processing delays into the network caused by converting signals from optical to electrical and back to optical form. Thus, the speed advantage associated with optical signal transmission was compromised by electronic switch processing. Moreover, these electronic switches have to be adapted for a given data rate and format within a communications network. Optical switches are transparent in that they allow signal transmission independent of data rate and format. Consequently, optical switching components as well as high speed electronic cross point switches are being developed to

accommodate increasing complexity associated with large optical communications networks.

Large optical or electronic switches can be constructed from smaller switches, for example, using the Clos Architecture. The basics of this type of switch are discussed in "A Study of Non-Blocking Switching Networks" by Charles Clos, The Bell System Technical Journal, March 1953, pp. 406-424. This type of switch requires at least three stages to provide connections from an input to a particular output from among all the possible connections within the switch which is referred to as "non-blocking." Fig. 1 is a block diagram illustrating a three stage switch 10 using the Clos Architecture. The input stage 15 of switch 10 includes Nx2N switching elements $20_1 \ldots 20_{2N}$, the intermediate stage 30 includes 2Nx2N switching elements $35_1 \ldots 35_{2N}$, and the output stage 40 includes 2NxN switching elements $45_1 \ldots 45_{2N}$ where N is an integer. The overall capacity of switch 10 is given by $2N^2$ by $2N^2$ where N is the number of inputs/outputs of each switch block 20. By way of example, where N =16, the Clos Architecture of Fig. 1 provides a switch capacity of 512 by 512 $(2(16)^2)$. Likewise, where N=32, the Clos Architecture provides a switch capacity of 2048 by 2048.

A drawback associated with these large switches is the number of inter-stage connections which must occur to provide for a non-blocking configuration. Because this number is so high, as described above, a physical mess of interconnections occurs between each stage of the switch. This can cause problems when attempting to trace a particular connection, for example, when a fault or break occurs or for system integration when partitioning back panel real estate. These and additional problems are an even greater concern when dealing with optical switches because of the special accommodations associated with fiber handling in optical interconnects since optical fiber may be bend sensitive.

United States Patent No. 4,910,730 entitled "Batcher-Banyan Network" issued on March 20, 1990 ("the '730 patent) discloses the arrangement of different types of integrated circuits to form a digital Batcher-Banyan network. In particular, horizontal and vertical stacks of merge subnetworks are interconnected to define the building blocks of a digital network which first sorts then routes data packets based on a particular bit within a destination address of each incoming packet. Because the '730 patent is limited to an

integrated circuit network, it does not discuss the use of optical switches nor does it address the problems associated with optical and electro-optical interconnects.

Thus, there is a need to provide a structure for simplifying interconnections between stages of large optical switches.

SUMMARY OF INVENTION

The present invention meets these needs and avoids the above-referenced drawbacks by providing a three dimensional optical switch interconnection structure for connecting a shuffle network which includes a first set of optical transmission members arranged in a first direction; a second set of optical transmission members arranged in a second direction; and a connection unit which couples each of the first set of transmission members to a corresponding one of the second set of transmission members.

In accordance with another aspect of the present invention, a method of interconnecting a multiple stage shuffle network is provided which comprises the steps of arranging a first set of optical transmission members from a first stage of the shuffle network in a first direction. Arranging a second set of optical transmission members from a second stage of the network in a second direction. Connecting the first set of transmission members to the second set of transmission members such that each of the second set of transmission members is connected to a corresponding one of the first set of transmission members. Configuring the first direction of the first set of transmission members in a perpendicular orientation with respect to the second set of transmission members.

In accordance with another aspect of the present invention an optical switch is provided which has $2N^2$ inputs and $2N^2$ outputs. The switch includes a first stage of switching elements each having 2N outputs, a second stage of switching elements each having 2N inputs, an interconnection unit disposed between the first and second stages. A first set of $4N^2$ optical waveguides couple the first stage and the interconnection unit where each of the waveguides carry an optical signal. The switch also includes a second set of $4N^2$ optical waveguides which couple the interconnection unit and the second stage. Each of these waveguides also carry an optical signal.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig.1 is a schematic illustration of a three stage Clos Switch Architecture.

Fig. 2 is a schematic illustration of an optical interconnect in accordance with the present invention.

DETAILED DESCRIPTION

Turning to the drawings in which like reference characters indicate the same or similar elements, Fig. 2 schematically illustrates a shuffle network interconnect 100 which may be used to connect input stage 15 with intermediate stage 30 and/or to connect intermediate stage 30 and output stage 40 of multistage switch 10 shown with reference to Fig. 1. Input stage 15 may receive optical signals from various sources. For example, each port of input stage 15 may receive a particular channel from a plurality of optical channels transmitted over a dense wavelength division multiplexed (DWDM) network. Input stage 20 may also be associated with SONET terminal receiving or transmitting equipment as well as the input to another switch stage or an additional optical switch. Similarly, output stage 40 may be used as the input to a DWDM network, SONET terminal receiving/transmitting equipment and/or the input to another stage of an optical switch.

Input stage 15, intermediate stage 30 and output stage 40 of switch 10 can include, for example, various types of optical or electrical switching elements $20_1 \ldots 20_{2N}$. Such optical switching elements include directional couplers, waveguide grating routers, etc. When optical elements are employed, the switching process and transmission of signals between the switching stages are in optical form. In addition, the inputs to and outputs from each of the stages in switch 10 can lie in substantially the same plane. For example, the input fibers to input stage 15 and the output fibers from input stage 15 can lie along the same plane. Similarly, the input fibers to intermediate stage 30 and the output fibers from intermediate stage 30 can lie along the same plane regardless of whether that plane is the same or different from the plane associated with the inputs and outputs of input stage 15. Output stage 40 can also be configured in the same manner.

Input stage 15, intermediate stage 30 and output stage 40 of switch 10 can also include electrical switching elements with optical transmitters and receivers at the

respective inputs and outputs of each stage. This configuration may be useful, for example, when the various stages of switch 10 are physically separated, thereby making electrical transmission between stages less advantageous. In this type of configuration, input stage 15 would include optical receivers at the input ports and optical transmitters at its output ports. The input stage receives signals in optical form, converts these signals to their electrical equivalent using, for example, a photodetector, performs the necessary switch processing, and converts the electrical signals to optical form by way of an optical emitter for transmission to intermediate stage 30 via optical fibers 38. The optical emitter can be, for example, a DFB laser, a VCSEL (vertical cavity surface-emitting laser), a Fabry Perot laser, or at lower data rates, relatively inexpensive light emitting diodes. The optical emitter can be externally modulated using, for example, a Mach-Zehnder interferometer or it can be directly modulated to produce optical signals corresponding to the electrical signals received from the switching elements.

Similarly, intermediate stage 30 may include optical receivers at its input ports and optical transmitters at its output ports. The intermediate stage 30 receives signals in optical form from input stage 15, converts these signals to their electrical equivalent, performs the necessary switch processing, and transmits the signals in optical form to output stage 30 via optical fibers 39. Finally, output stage 40 can also include optical receivers and transmitters at its input and output ports respectively. Output stage 40 receives signals in optical form from intermediate stage 30, converts these signals to their electrical equivalent, performs the necessary switch processing and transmits the signals in optical form to output stage 30 via optical fibers 39. The necessary transmitters, receivers and switching components are well known in the art. Alternatively, the various stages of switch 10 can include a combination of electrical switching elements, having optical transmitters and receivers, and optical switching elements to form a type of hybrid switching configuration.

The shuffle network interconnection 100 shown in Fig. 2 in accordance with the present invention can be used for any of the above described configurations. The network interconnection illustrated in Fig. 2 is associated with a simplified switch where N=4, thereby providing 64 connections between input stage 15 and intermediate stage 30 or between intermediate stage 30 and output stage 40. It should be understood that this

simplified interconnection and associated description is being used for ease of explanation. However, this description should not be taken as limiting the number of stages or the number of interconnections between the stages in accordance with the principals of the present invention.

The shuffle network interconnection 100 includes a first set of optical waveguides 105, a first connector housing 110, a second connector housing 115 and a second set of optical waveguides 120. The first set of optical waveguides 105 can include a plurality of optical fibers connected at one end, for example, to intermediate stage 30 of switch 10 and at the other end to a first connector housing 115. The first set of optical waveguides 105 comprise a plurality of N ribbon cables 125 arranged horizontally in an 2Nx2N array similar to books on a bookshelf. In this example, the first set of optical waveguides 105 includes 8 ribbon cables, each cable including 8 fibers $140_1 \ldots 140_N$ (where N=4) to define 64 $(2N)^2$ connections arranged in an 8x8 array.

The second set of waveguides 120 has a first end coupled to connector housing 115 and a second end connected, for example, to output stage 40 of optical switch 10 shown with reference to Fig. 1. The set of waveguides 120 can comprise a plurality of N ribbon cables 130 stacked vertically in an 2Nx2N array. In this example, 8 ribbon cables are used where each cable includes 8 fibers $145_1 \ldots 145_N$ to define 64 connections in an 8x8 array. The first and second sets of waveguides can carry optical wavelengths, for example, within the 1.3μm or 1.5 μm range, corresponding to minimum signal attenuation associated with silica-based fibers.

The first connector housing 110 and second connector housing 115 are adapted to receive one end of the first set of waveguides 105 and the second set of waveguides 120, respectively. Connector housings 110 and 115 are configured such that, for example, fiber 140_N of the first set of waveguides 105 is coupled to fiber 145_1 of the second set of waveguides 120. Ribbon cables 125 and 130 may be used, however individual fibers or fiber cables may also be employed. In addition, the use of connector housings 110 and 115 provides a suitable optical connector to couple each fiber from the first set of optical waveguides 115 to fibers included in the second set of optical waveguides 120.

Connector housings 110 and 115 can be combined to form a connecting unit 150 which may take on alternative embodiments. In particular, connecting unit 150 may

comprise a free space region 160 disposed between housings 110 and 115. Light traveling from the first set of waveguides 105 is directed to the second set of waveguides 120 and traverses free space region 160. Alternatively, free space region 160 may be eliminated and connector housing 110 may be coupled directly to connector housing 115.

While the foregoing invention has been described in terms of the embodiments discussed above, numerous variations are possible. Accordingly, modifications and changes such as those suggested above, but not limited thereto, are considered to be within the scope of the present invention.

What is claimed is:

1. A multi-stage optical switch interconnection structure for connecting a first and second stages of a shuffle network, said apparatus comprising:

a first set of optical transmission members arranged in a first direction, said first set of optical transmission members carrying optical signals;

a second set of optical transmission members arranged in a second direction, said second set of optical transmission members carrying optical signals; and

a connecting unit coupling each of said first set of transmission members to a corresponding one of said second set of transmission members.

2. . The structure in accordance with claim 1 wherein said first direction is perpendicular to said second direction.

3. The structure in accordance with claim 1 wherein said first set of optical transmission members defines a 2Nx2N array.

4. The structure in accordance with claim 1 wherein said second set of optical transmission members defines a 2Nx2N array.

5. The structure in accordance with claim 3 wherein said connecting unit comprises:

a first housing configured to receive said first set of optical transmission members; and

a second housing configured to receive said second set of optical transmission members.

6. The structure in accordance with claim 5 wherein said connecting unit further comprises a free space region disposed between said first and second housing such that optical signals from each of said first set of transmission members is directed to a corresponding one of said second set of transmission members through said free space region.

7. The structure in accordance with claim 1 wherein said first set of optical transmission members comprise a plurality of ribbon cables, each of said ribbon cables including 2N optical fibers oriented in a side-by-side relationship.

8. The structure in accordance with claim 1 wherein said second set of optical transmission members comprise a plurality of ribbon cables, each of said ribbon cables including 2N optical fibers oriented in a side-by-side relationship.

9. The structure in accordance with claim 1 wherein said first set of optical transmission members comprise 2N ribbon cables, each of said 2N ribbon cables including 2N optical fibers oriented in a side-by-side relationship.

10. The structure in accordance with claim 1 wherein said second set of optical transmission members comprise 2N ribbon cables, each of said 2N ribbon cables including 2N optical fibers oriented in a side-by-side relationship.

11.. A method for interconnecting a first and second stages of an optical shuffle network comprising the steps of:

arranging a first set of optical transmission members from said first stage of said network in a first direction;

arranging a second set of optical transmission members from said second stage of said network in a second direction; and

connecting said first set of optical transmission members to said second set of optical transmission members such that each of said second set of optical transmission members is connected to a corresponding one of said first set of transmission members.

12. The method in accordance with claim 11 wherein said first direction is perpendicular to said second direction.

13. An optical switch having $2N^2$ inputs and $2N^2$ outputs, said optical switch comprising:

a first stage of switching elements each of said switching elements having 2N outputs;

a second stage of switching elements each of said switching elements having 2N inputs;

an interconnection unit disposed between and coupling said first and second stages;

a first set of $(2N)^2$ optical waveguides, each of said waveguides having a first end coupled to said first stage and a second end coupled to said interconnection unit, said first

set of optical waveguides oriented in a second direction, each of said waveguides carrying optical signals; and

a second set of $(2N)^2$ optical waveguides, each of said waveguides having a first end coupled to said interconnection unit and a second end coupled to said second stage, said second set of optical waveguides oriented in a first direction wherein each of said first set of optical waveguides is connected to a corresponding one of said second set of optical waveguides, each of said second set of waveguides carrying said optical signals.

14. The optical switch in accordance with claim 13 wherein said interconnection unit comprises a first connection housing configured to receive each of said second ends of said first set of optical waveguides.

15. The optical switch in accordance with claim 14 wherein said interconnection unit comprises a second connection housing configured to receive each of said first ends of said second set of optical waveguides.

16. The optical switch in accordance with claim 15 wherein said interconnection unit further comprises a free space region disposed between said first and second interconnection units, said optical signals traveling from said first connection housing through said free space region to said second connection housing.

17. The optical switch in accordance with claim 15 wherein said first connection housing is physically coupled to said second connection housing.

18. The optical switch in accordance with claim 13 wherein said first stage of switching elements is configured to process optical communication signals.

19. The optical switch in accordance with claim 13 wherein said second stage of switching elements is configured to process optical communication signals.

20. The optical switch in accordance with claim 13 wherein said first stage of switching elements is configured to process electrical communication signals.

21. The optical switch in accordance with claim 13 wherein said second stage of switching elements is configured to process electrical communication signals.

22. The optical switch in accordance with claim 20 wherein each of said switching elements further comprises:

an optical receiver;

an optoelectronic conversion device coupled to said optical receiver, said optoelectronic device receiving optical communication signals from said optical receiver and generating electrical signals in response thereto;

at least one electronic switch for receiving said electrical signals and switching said signals to one of a plurality of outputs associated with said switching elements; and

an optical emitter for generating optical signals in response to said electrical signals received from said electronic switch, said optical emitter supplying said optical signals to said first end of said first set of optical waveguides.

23. The optical switch in accordance with claim 21 wherein each of said switching elements further comprises:

an optical receiver;

an optoelectronic conversion device coupled to said optical receiver, said optoelectronic device receiving optical communication signals from said optical receiver and generating electrical signals in response thereto;

at least one electronic switch for receiving said electrical signals and switching said signals to one of a plurality of outputs associated with said switching elements; and

an optical emitter for generating optical signals in response to said electrical signals received from said electronic switch, said optical emitter supplying said optical signals to said second end of said second set of optical waveguides.

24. The optical switch in accordance with claim 13 wherein said first stage of switching elements further comprises N inputs, said 2N outputs and said N inputs being configured such that said N inputs and 2N outputs lie in the same plane.

25. The optical switch in accordance with claim 13 wherein said second stage of switching elements further comprises N outputs, said 2N inputs and said N outputs being configured such that said 2N inputs and said N outputs lie in the same plane.

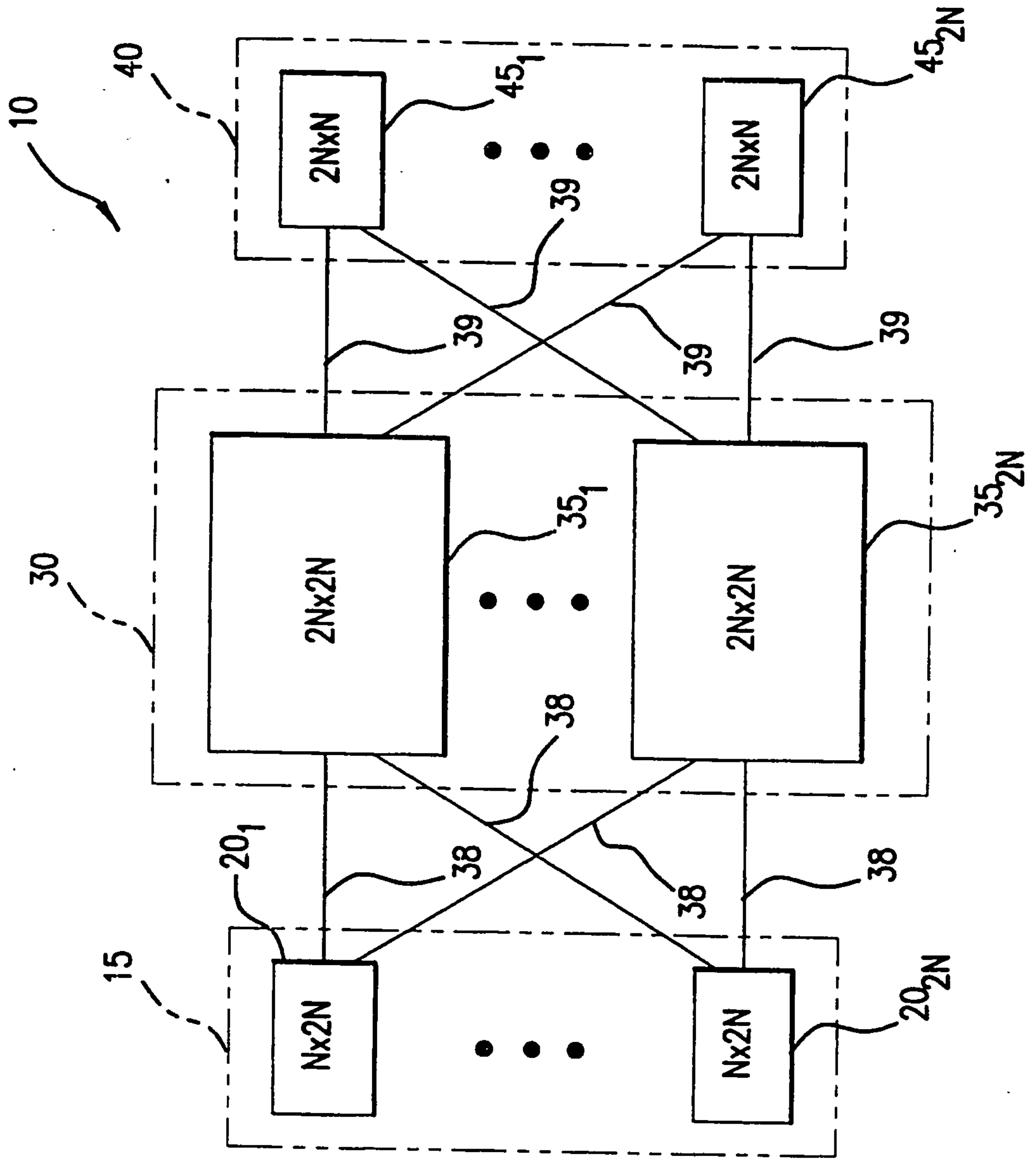
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FIG. 1

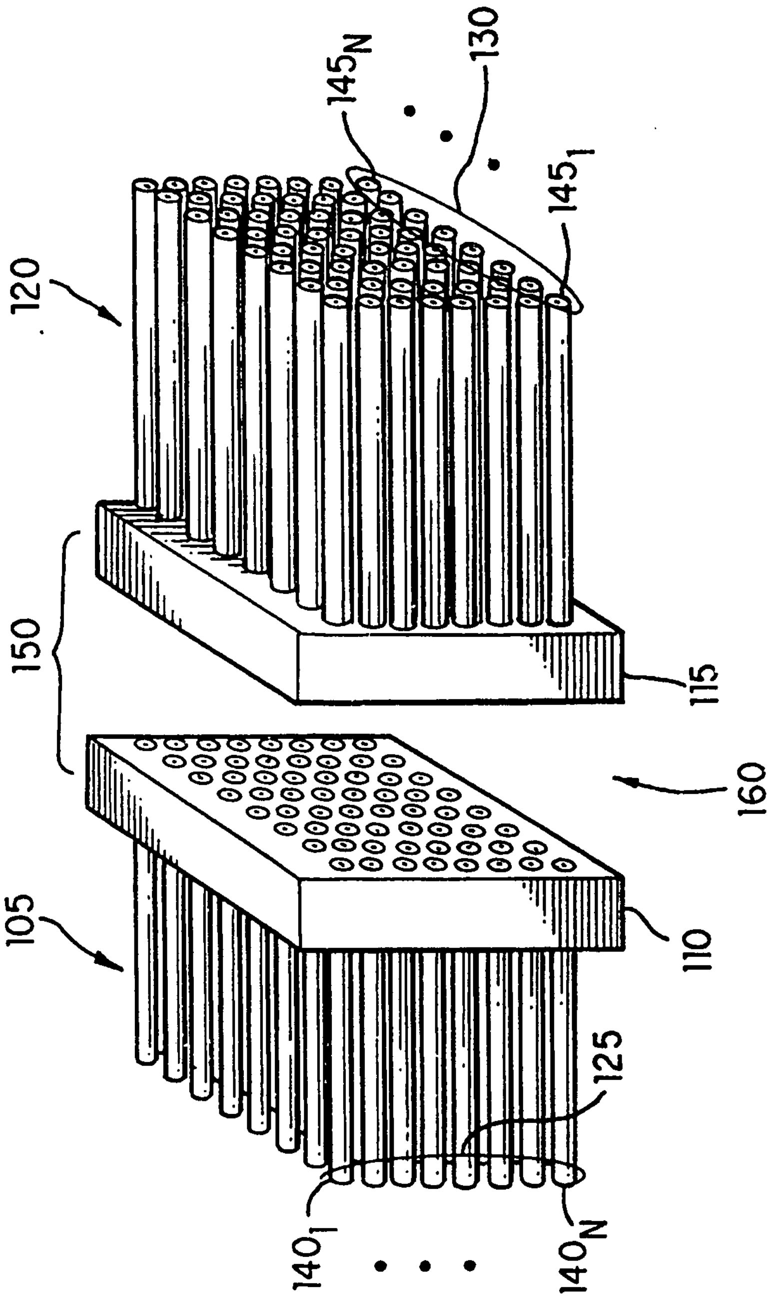

FIG. 2

INTERNATIONAL SEARCH REPORT

Inte[rnatio]nal Application No
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A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 H04Q3/52 G02B26/02

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 H04Q G02B H04L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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28 June 1999	05/07/1999

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International Application No
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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

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